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CONSIDERATIONS IN THE DESIGN AND DEVELOPMENT OF A SPACE STATION SCALE MODEL

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INTRODUCTION

The paper reviews preliminary work at the Langley Research Center (LaRC) related to the design, analysis and testing of a Space Station scale model. Included are some rationale for focusing the scale model program on Space Station and the utilization of the model to achieve the program objectives. In adddition, some considerations involved in designing a dynamics scale model, such as ground test facilities, sub-scale component fabrication and model replication vs. simulation are presented. Finally, some related research areas currently ongoing at LaRC in support of scale model development are discussed.

TALK OUTLINE

- OVERVIEW OF LaRC SCALE MODEL PROGRAM
- UTILIZATION OF SCALE MODEL
- SCALING CONSIDERATIONS
- RELATED RESEARCH

LaRC SPACE STATION MODEL PROGRAM

The major objective of the LaRC scale model program is to develop technology to improve our ability to predict the on-orbit structural dynamics of large, flexible, multi-bodied, and articulated spacecraft. The approach taken is to develop the technologies for using properly scaled structural models to provide confidence for verification and control of full scale structures which are too large to be tested in the earth's 1-g environment. To this end, the project will fabricate a near replica scale model of Space Station and conduct a comprehensive ground test/analysis program to characterize the structural dynamics of the model. The resulting analysis will then be used to predict the in-orbit behavior of the full scale structure. Finally, via a correlation of the model results with flight data obtained during on-orbit assembly and testing of Space Station, verified analysis and ground test methodologies for other structutres of this class will be developed.

LaRC SPACE STATION SCALE MODEL PROGRAM

OBJECTIVES:

Develop technology which provides a verified capability to predict on–orbit structural dynamics of large, multi–bodied spacecraft.

APPROACH:

Fabricate a near–replica scale model of Space Station.

Conduct comprehensive ground test–analysis technology program.

Correlate results with full scale flight data from on–orbit testing.

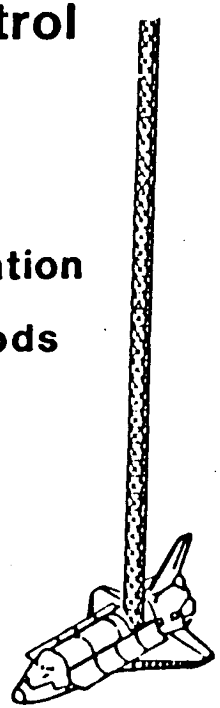
THE CONTROL OF FLEXIBLE STRUCTURES (COFS) PROGRAM

The development of the scale model resides under the COFS III project at LaRC. COFS III is the third in a series of three major projects under the Control of Flexible Structures (COFS) Program. The COFS program consists of a series of detailed ground and flight test/analysis projects on a variety of large space strucrures. COFS III emphasizes multi-body dynamics and control and focuses on a class of structures which are too large to be properly tested beyond the component/subassembly level in the earth's 1-g environment. Technology derived from COFS I and II will transfer directly to COFS III, especially in the areas of developing testing techniques and characterizing multi-jointed structures.

CONTROL OF FLEXIBLE STRUCTURES

COFS I

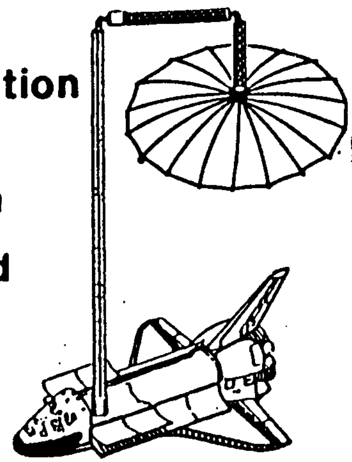
Beam Dynamics & Control



- Systems Identification
- Test Methods
- Distributed Controls

COFS II

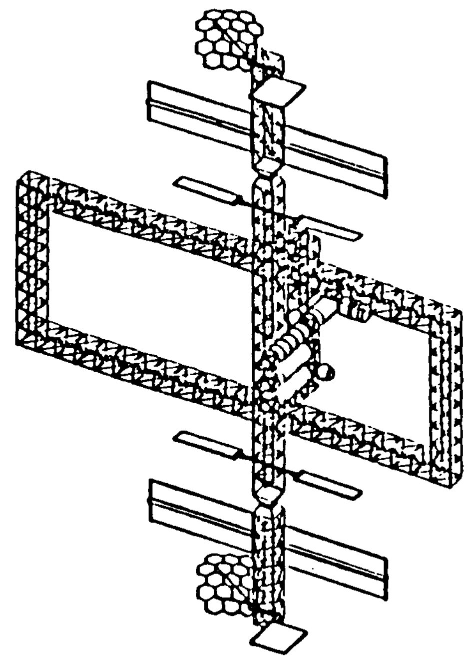
Three-Dimensional Dynamics & Control



- Systems Identification
- Shape Definition
- Distributed Controls
- Adaptive Controls

COFS III

Multi-Body Dynamics & Control



- Test Methods
- Systems Identification
- Model Sensitivities
- Analysis Validation
- Space Station Supporting Technology

MOTIVATION FOR SPACE STATION AS COFS III FOCUS

The Space Station is an excellent example of future generation multi-bodied structures requiring validated structural dynamics and control analyses, thus it serves as a natural focus for the COFS III project. A scale model ground test/analysis program addresses the key technologies of the COFS Program including development of verified analyses, ground test methods, and spacecraft vibration suppression methods. Unlike COFS I and II, COFS III does not contain an orbital test as part of the project; however, the expected availability of flight test data from the full scale station in orbit will allow the correlation between ground and flight tests necessary to verify analyses. Furthermore, the scale model provides a means for conducting technology development tests and examining the response of evolutionary configurations and/or alternative component combinations prior to flight.

MOTIVATION FOR SPACE STATION AS COFS III FOCUS

- SS is large, flexible, joint–dominated, multi–bodied, and articulated → provides great challenges in structural dynamics and control.

- Addresses key COFS technology goals
  - Development of verified analyses for multi–bodied spacecraft
  - Extend current ground test methods
  - Development of vibration suppression and control methods

- Availibility of full scale test data to correlate model ground test results and analytical predictions on complex structure.
  - Ground tests of key subassemblies
  - On–orbit flight test data

- Follow–on COFS activities through support of evolutionary SS configurations and technology development tests.

JUSTIFICATION FOR SCALE MODEL DYNAMIC GROUND TESTS

A major justification for ground tests of scale model hardware is the reduction of the effects of gravity and size on full-scale ground tests. For many large space structures, scale models offer the only opportunity to achieve fully mated test data prior to flight, which could help uncover potential problems or verify designs and mathematical models. Scale models can also be useful in determining instrumentation requirements and optimum placement on the full scale vehicle and for studying anticipated flight maneuvers and investigating flight anomalies. Finally, as specifically related to Space Station, the model provides a test bed for robotics experiments and for studying potential growth configurations.

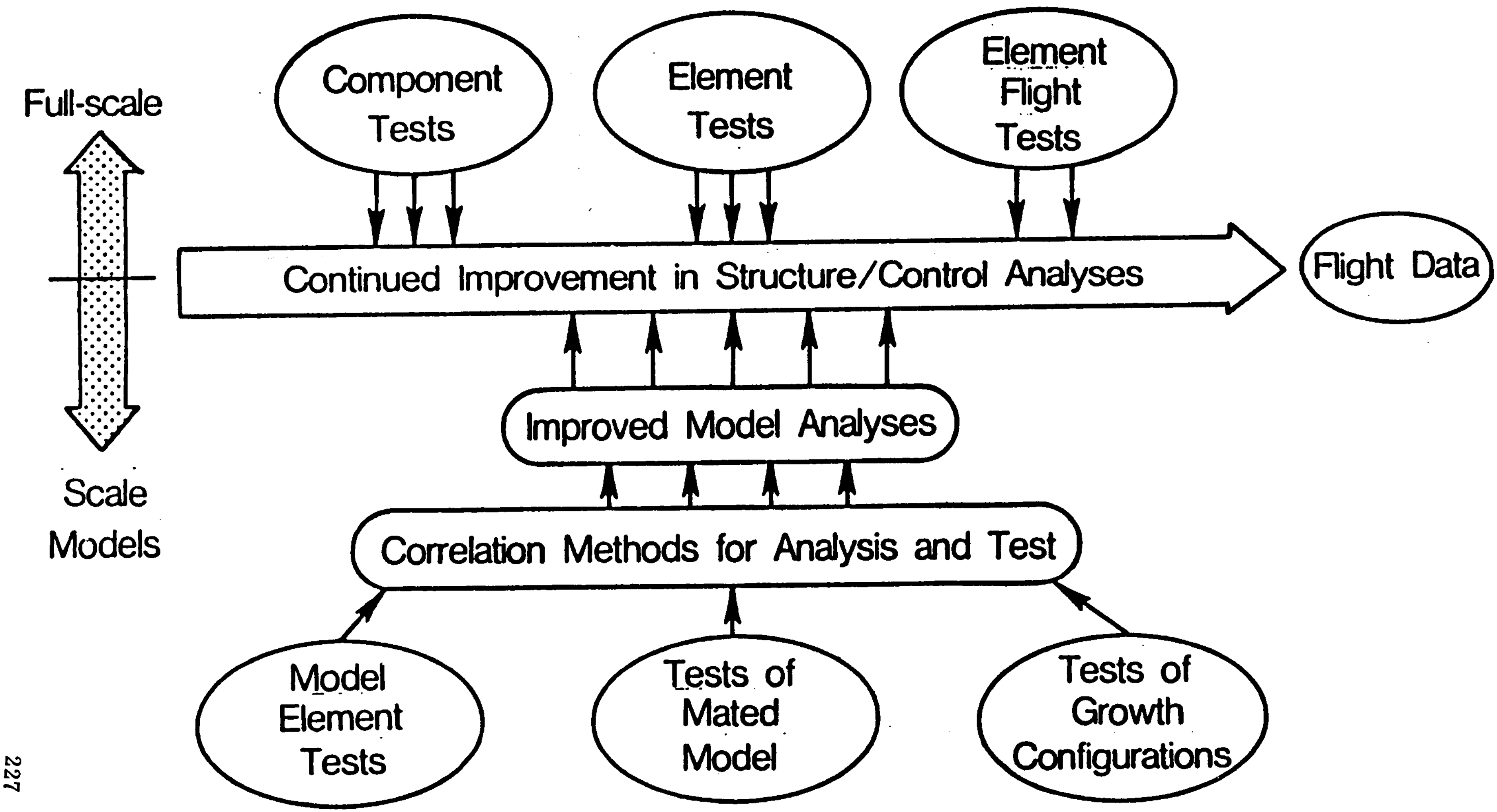
JUSTIFICATION FOR SCALE MODEL DYNAMIC GROUND TESTS

- Fully mated full scale ground tests are desirable but not possible due to gravity and large size.
- Significant improvements in analysis capability possible through:
  - Hands–on experience with realistic hardware
  - Acquisition of mated vehicle data prior to flight
- Uncover potential problems which influence design.
- Pilot for examining instrumentation requirements of orbiting station.
- Tool for studying anticipated flight maneuvers and investigating flight anomalies.
- Test bed for MRMS and robotics operations.

APPROACH FOR OBTAINING QUALIFICATION OF MATH MODELS

An approach for obtaining verified analytical models is shown in the adjoining chart. The scale models are used to develop methods for correlating analyses with tests of model components and mated configurations. The full scale hardware is limited to component and element testing and perhaps flight tests of some hardware. Once the full scale vehicle is in orbit, flight data can be used for the final adjustments to the scale-model-verified analyses to obtain a fine-tuned representation of the full-scale vehicle on-orbit behavior.

APPROACH FOR OBTAINING QUALIFICATION OF MATH MODELS



COFS III GROUND TEST SCENARIO

The ground test scenario for the COFS III project includes three levels. First, the scaling of elements such as structural joints and truss members along with analytical characterization of these elements. Second, major subassemblies of the full structure will be tested and systems identification performed to identify the characteristics of those subassemblies and make adjustments of analyses. The scale model will be modular in design such that all anticipated full scale assembly scenarios can be duplicated on the ground prior to flight. In addition, the scale model will undergo the same types of tests anticipated for the full-scale structure (i.e., static/dynamic tests of major subassemblies) in order to obtain as many comparisons between model and full-scale test data as possible. Third, fully-mated scale model ground tests will be performed on both IOC and any growth versions.

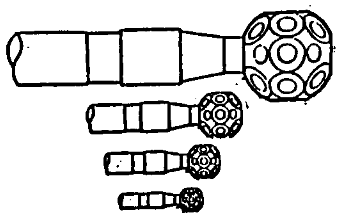
COFS III GROUND TEST SCENARIO

SCALE MODEL TECHNOLOGY

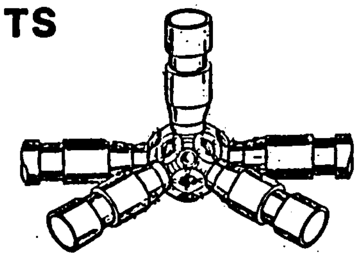
LEVEL I

Elements

SCALING



JOINTS



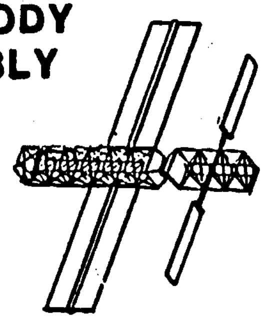
DAMPING

LEVEL II

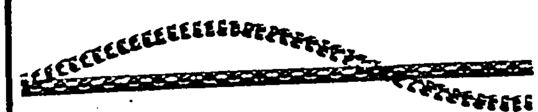
Subassembly

TRUSS STRUCTURE

MULTI-BODY ASSEMBLY

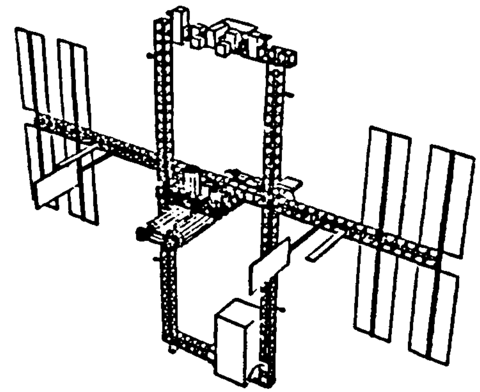


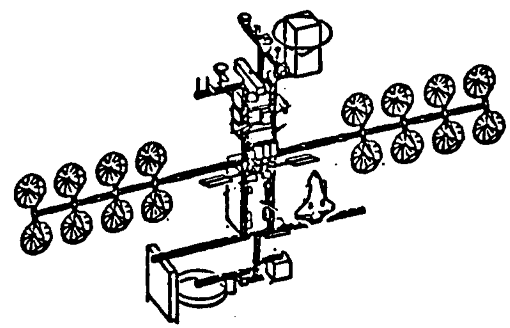
SYSTEMS IDENTIFICATION



LEVEL III

Mated/Growth





DYNAMIC MODEL SCALING

The optimum scale factor for a dynamics model is a trade-off between how well the individual model components can be manufactured at sub-scale and how large a model can be tested inside the available test facility. Manufacturing limitations would tend to increase the model size (provides lower bound) while simultaneously the limited size of conventional test facilities tend to decrease the model size (provides upper bound). Another major factor in dynamic model scaling is the identification of components which require replication and those for which only require mass and inertia simulation. For the COFS III model, components such as the joints, truss members as well as interfaces between major subsystems or payloads and the structure will likely require replication: however, model cost and complexity can be reduced by simulating modules, major subsystems, and payloads.

DYNAMIC MODEL SCALING

- Optimum model scale factor is a trade–off.
  - Advantages of decreasing model size
    - Gravity effects reduced
    - Eases facility, suspension, and instrumentation reqmts.
    - Improves model handling (weight)
  - Disadvantages of decreasing model size
    - Fabrication process more difficult
    - Component replication more critical (tolerances)
    - Creates handling problems (fragility)

- Ground test facility crucial to achieve meaningful test data.
  - Facility size provides upper bound on model size.
  - LSL satisfies volume and suspension requirements

- Component Replication vs. Simulation
  - Replication desirable for stiffness/damping properties

    Joints

    Tubular Members

    Interfaces
  - Reduce model cost and complexity thru simulation

    Modules

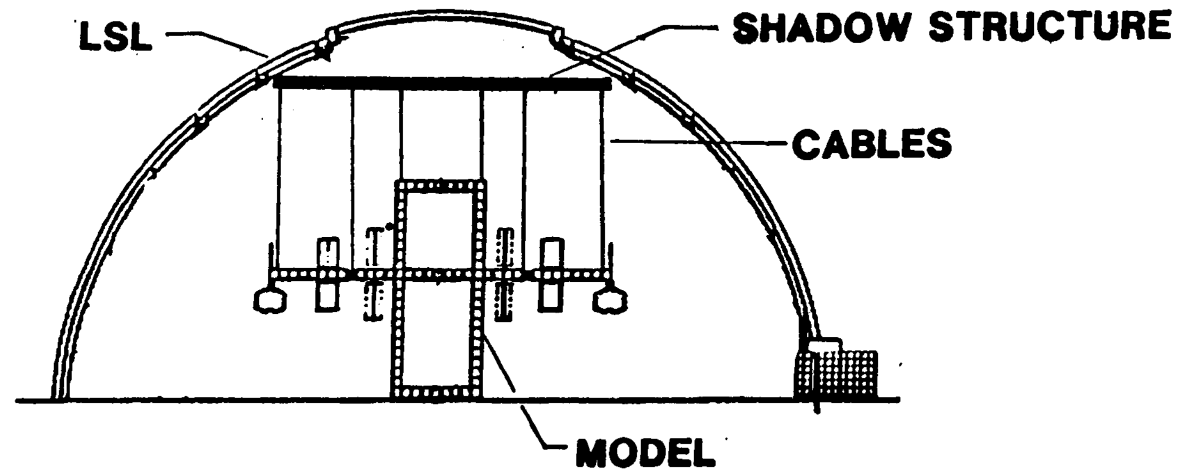
    Subsystems

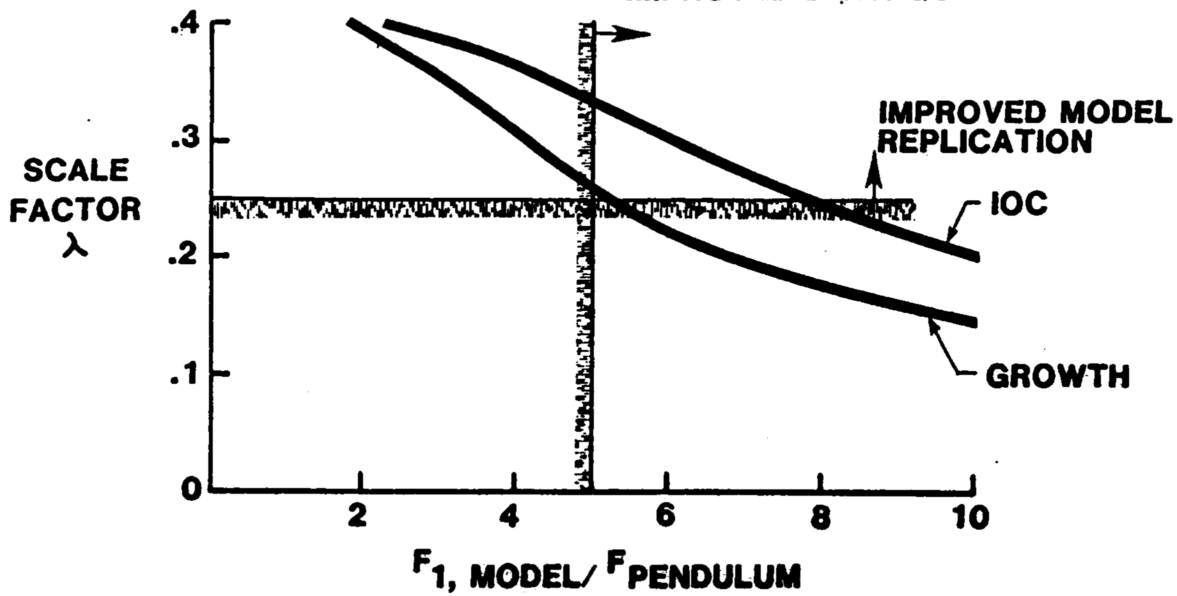
    Payloads

EFFECT OF SCALE FACTOR ON MODEL FREQUENCY TO PENDULUM FREQUENCY RATION

Pendulum suspensions on long cables are the most likely technology for supporting models during tests, especially in complete system configurations. Examining the effect of scale factor on the model-frequency-to-suspension-pendulum-frequency ratio provides a means for identifying a reasonable range for the scale factor. Shown on the adjoining chart is the variation of frequency ratio with model scale factor for an initial and a growth configuration of the scale model tested verticallly. The acceptable design region is the upper right quadrant such that the scale factor is above the assumed manufacturing limitation of .25 and the frequency ratio is above the desired value of 5.

EFFECT OF SCALE FACTOR ON MODEL FREQUENCY TO PENDULUM FREQUENCY RATIO

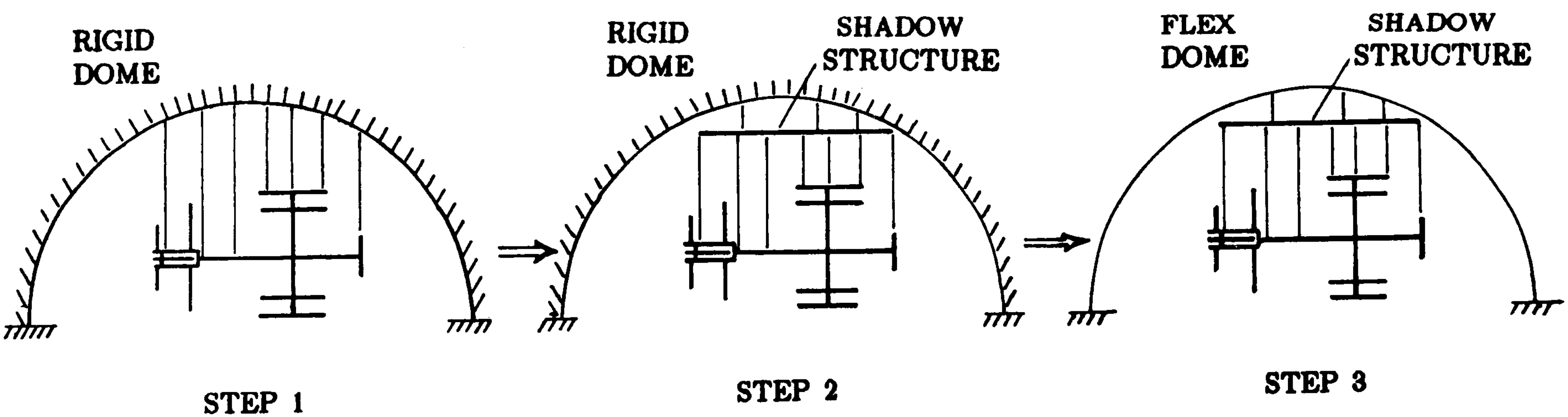




ASSESSMENT OF SUSPENSION CABLES ON SCALE MODEL TESTING

A key issue in the area of ground test methods was addressed in a study of the interaction of the scale model with a candidate suspension system and proposed test facility. Depicted in the adjoining chart are the 3 steps used to study these effects. Note this study was initially performed on a single keel configuration; however, the conclusions reached are expected to be similar for the dual keel station. A first step is to suspend the model from cables which connect directly to the top of the test facility (assumed to be rigid). Next, a shadow structure concept is used whereby the model is suspended from the rigid shadow structure, which covers the model planform, and the shadow structure is in turn suspended from the test facility (also assumed to be rigid). This concept provides maximum versatility in locating cable attachment points. Finally, step 3 involves accounting for the flexibility of the dome in the analysis procedure. Initial analyses have shown the effects of the dome flexibility on the model dynamics to be negligible, thus most analyses to date have focused around step 2.

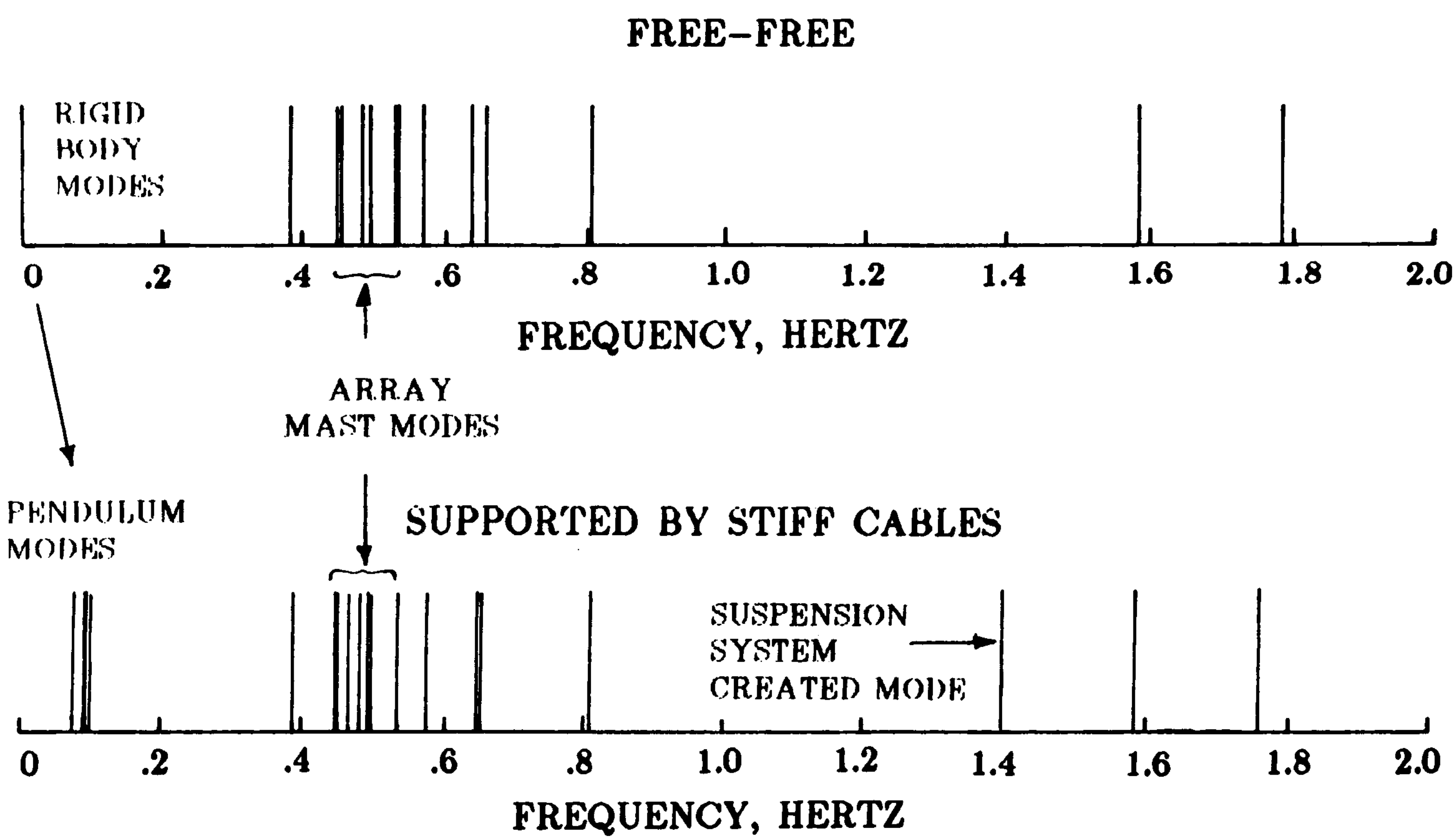
ASSESSMENT OF SUSPENSION CABLES ON SCALE MODEL TESTING



MODAL DENSITY OF 1/3 SCALE SPACE STATION MODEL

A comparison between the modal density of a 1/3 scale model analyzed in a free-free condition and the same model analyzed as suspended in a pendulum configuration is shown in the adjoining chart. The results of the supported case represent a superposition of suspending the model both vertically and horizontally in order to extract both in-plane and out-of-plane modes. The free-free rigid body modes become pendulum modes in the supported case. The natural frequencies of these models are well separated from those of the structural modes, thus there were no interactions evident. Furthermore, there were no significant changes in structural frequencies due to the suspension system and all free-free modes were identifiable.

MODAL DENSITY OF 1/3 SCALE SPACE STATION MODEL



NOTE – FULL SCALE FREQUENCIES = MODEL FREQUENCIES / 3

RELATED RESEARCH AREAS

The Structural Dynamics Branch, Structures and Dynamics Division, of the Langley Research Center is involved in a variety of research areas directly applicable to the scale model program. One such area is the study of active member dampers which could be placed in the truss members of a truss structure to provide vibration suppression. This is one concept currently envisioned for introducing a vibration suppression mechanism into the scale model. Another effort is an on-going evaluation of in-house capability to manufacture model components such as structural joints and graphite/epoxy tubular members. In addition, ground test methods for large multi-jointed structures are being developed by conducting tests (static and dynamic) of prototype Space Station hardware.

RELATED RESEARCH AREAS

- Application of active member dampers for vibration suppression of truss structures
- Evaluate model fabrication capabilities
  - Structural joints
  - Gr/Ep tubular members
- Improve ground test methods
- Examine suspension system effects on scale model

SPACE STATION SCALE MODEL RESEARCH HARDWARE

Some of the research hardware used in LaRC's in-house scale model efforts are shown in the adjoining photo. Two seven-bay erectable truss structural models have been built under contract, one at full scale (15-foot bays) and one at 1/4 scale. These models have been assembled in various configurations to demonstrate the versatility of the erectable concept. Currently these structures are undergoing testing at LaRC. These tests include static tests of the joint components to characterize joint stiffness and modal testing to characterize frequencies and mode shapes.

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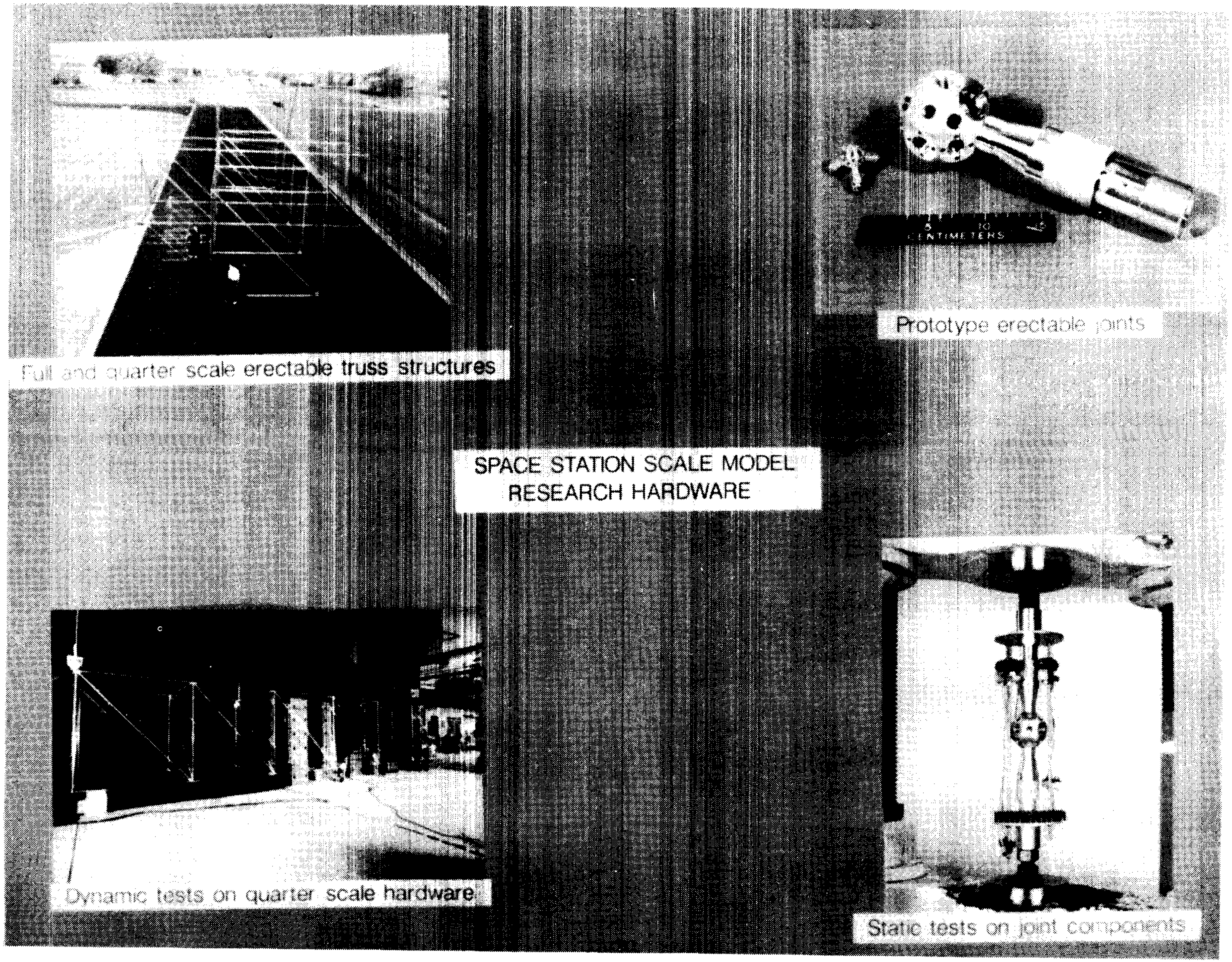
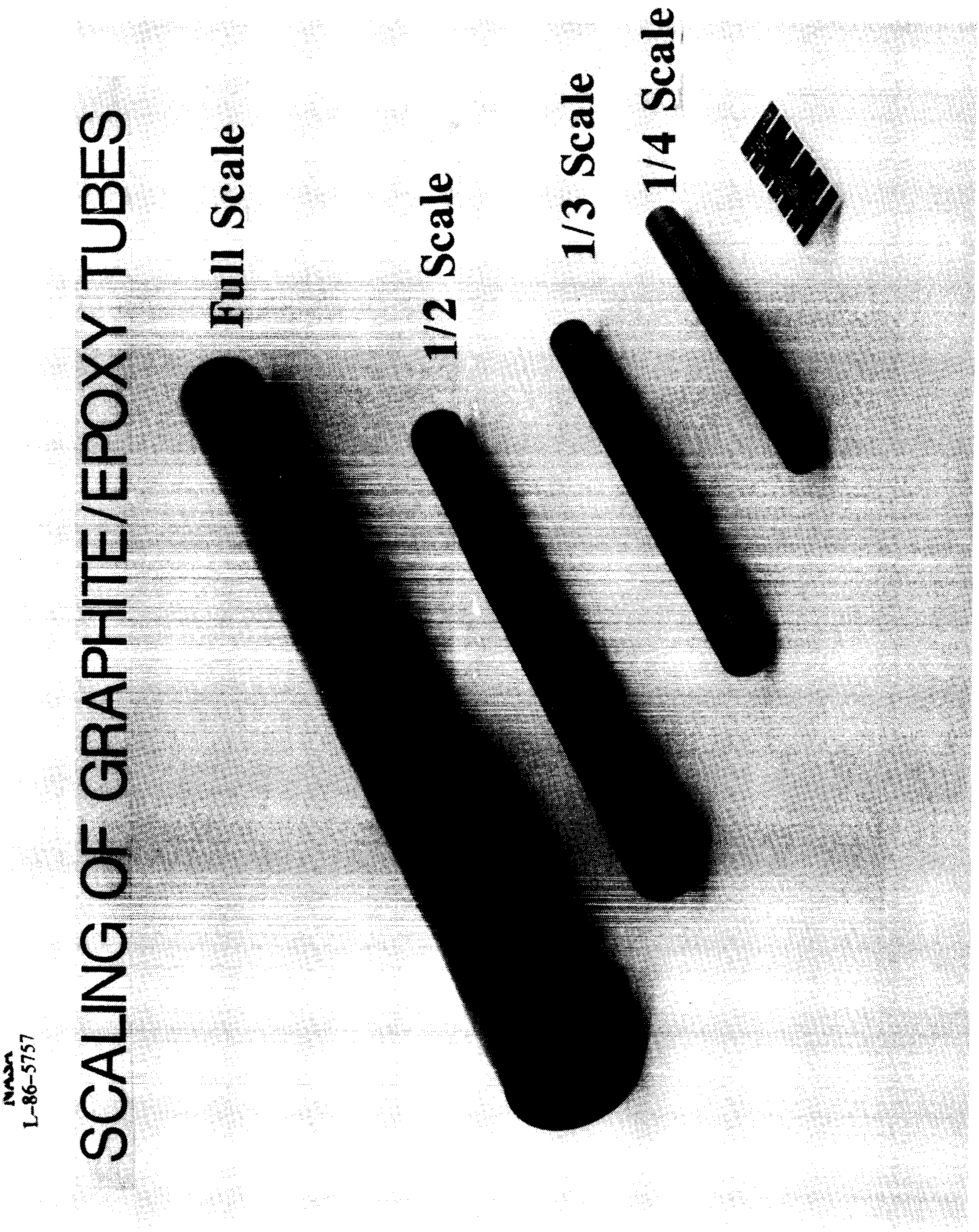


SCALING OF GRAPHITE/EPOXY TUBES

In addition to fabricating subscale joint components, recent efforts have focused on studying the manufacturability and scalability of graphite/epoxy (gr/ep) tubes currently proposed for Space Station truss members. The photo shows a series of gr/ep tubes fabricated at full (2 in. O.D., .060 in. wall), 1/2, 1/3, and 1/4 scales such that the aspect ratio of each tube remains constant. The tubes will undergo a series of static and dynamic tests to examine the degree of replication provided by the manufacturing process at each scale.


SCALING OF GRAPHITE/EPOXY TUBES
Full Scale
1/2 Scale
1/3 Scale
1/4 Scale
NASA
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A summary of LaRC's plans for the development of a Space Station scale model has been presented. The purpose of this program is to develop technology for better predicting the structural dynamics and control of large multi-bodied spacecraft. The focus, Space Station, provides an opportunity for comparing the ground test/analysis results with full-scale orbital data which will be obtained for other purposes in the Space Station development effort. Several issues which affect the scale factor determination were discussed along with research aimed at each of those issues.

CONCLUDING REMARKS

- Focus problem addresses COFS goals with opportunity to support Space Station, IOC and beyond.
- Scale model viable method to achieve validated full–scale analysis.
- Scale factor determination a trade–off between fabrication and facility/suspension limitations.
- Greatest fabrication challenges in areas of structural joints and tubular members.
- Preliminary studies indicate suspension system/model interactions can be analytically extracted.